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The effect of artificial discontinuties on recent trends in minimum and maximum temperatures

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The effect of artificial discontinuities on recent trends in minimum and maximum temperatures

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Abstract

A number of recent papers have focused in the asymmetric rise in minimum vs. maximum temperatures for various parts of the globe. Here we re-examine this question in order to determine the effects of inhomogeneities on the results. We apply a inhomogeneity detection and adjustment technique we have developed for individual station time series. Results show the effects on large-area (hemispheric) aggregate time series to be small. However, much larger effects are found when smaller regions are examined.

1. Introduction

Much of the early ''global warming'' research focused solely on trends in mean temperature (e.g. Jones et al., 1986). Monthly mean temperatures are usually calculated from mean monthly maximum and minimum temperatures which in turn are derived from daily observations of maximum and minimum temperature. A trend in mean temperature may be caused by caused by changes in either minimum or maximum temperatures or both. The first evidence that maximum and minimum temperature may have different trends over the past century were outlined by Karl et al. (1984) who looked at rural maximum and minimum temperatures for parts of North America. More recently, a number of studies have included data for other parts of the world including the former Soviet Union, Peoples Republic of China and parts of Europe and Africa (Karl et al., 1991, 1993). These studies have supported earlier findings that, in general, the minimum temperatures are rising at a faster rate than maximum temperatures leading to a decrease in the diurnal temperature range (DTR). However, much of the data used in these studies have not been thoroughly analyzed for inhomogeneities in the station temperature time series.

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A homogeneous climatic time series has been defined where all variation is due only to variations in weather and climate (Conrad and Pollack, 1950). Inhomogeneities in temperature time series generally occur either as trends due to artificial changes in the landscape surrounding the station, as in the case of urban warming, or they occur as abrupt discontinuities. Abrupt discontinuities generally occur for reasons such as station relocations, instrument changes, or changes in averaging methods. These changes may be random in their effects so that discontinuities with warm biases are often assumed to cancel out discontinuities with cool biases when time series are aggregated into areal average time series. However, non-random changes in location (e.g. movements from urban to rural airport locations), or in instrument types (e.g. liquid in glass thermometers to thermistors) may cause biases to be consistently in the same direction (e.g. all warm or all cool) at many or even all stations in a network. While the stations used in Karl et al. (1993) were carefully selected to minimize these influences, it is impossible to avoid completely all stations that undergo such changes and still have enough stations to produce robust estimations of regional trends. Furthermore, it is also impossible to determine if a time series is truly homogeneous as defined above. Therefore, in this paper we define homogeneity in terms of what Conrad and Pollack (1950) have defined as "relative homogeneity"; that a station has been compared to surrounding stations and found to be consistent with variations at those neighboring stations.

A number of strategies have developed in the past few years in order to account for the problem. Both subjective and objective methods have been proposed and applied to temperature time series in order to determine whether the data for an individual station are homogeneous. Jones et al. (1986) and Rhoades and Salinger (1993) both used a subjective methodology where the time series for individual stations were plotted with neighboring stations, and a subjective assessment made regarding homogeneity and the need for data adjustments. More objective tests have been proposed and applied by Potter (1981), Alexandersson (1986), and Gullet et al. (1991) where discontinuities are identified statistically. Recently, in Easterling and Peterson (1995) we presented the results of an assessment of the performance of these techniques, and a new technique we developed. We found our technique to be the most robust of those evaluated and when used with a methodology for creating homogeneous reference series presented in Peterson and Easterling (1994), it can be used to provide homogeneous temperature time series. This technique was developed for use on the Global Historical Climatology Network (GHCN; Vose et al., 1992) mean monthly temperature data but it also works well with monthly mean maximum or minimum temperature.

The question we attempt to address in this paper is: are the recent observed trends in minimum and maximum temperature accurate reflections of changes in climate or are they due to non-random discontinuities in the temperature time series? To evaluate this problem we applied our objective inhomogeneity detection and adjustment technique to the maximum and minimum temperature data for the majority of the Northern Hemisphere and reanalyzed the data looking for changes in trends.

2. Methods

The first step in our homogeneity testing is to create a homogeneous reference time series for each station using nearby stations (Peterson and Easterling, 1994). Next a difference

series is created by subtracting the time series for the station being tested from its reference series. The technique then tests the difference series for changes in statistical characteristics (in this instance we test for a change in the mean of the difference series) indicating a discontinuity (Easterling and Peterson, 1995). Lastly, the magnitude of the inhomogeneity is determined and an adjustment is made to the station data to account for the discontinuity.

We applied this technique to seasonal and annual minimum and maximum temperature data from Russia, China, Canada, Japan and the United States (including Alaska but excluding Hawaii). This created a data set covering much of the Northern Hemispheric land surface where much of the effects of inhomogeneities such as station moves, changes in instrumentation, and changes in station environment, have been systematically and objectively removed. A couple of further notes are that we removed stations where the adjustment values exceeded 3°C. Furthermore, when the dT/dt (year to year change in temperature; Peterson and Easterling, 1994) correlation coefficient for the subsection of the time series surrounding a particular discontinuity was less than 0.60 we did not make the adjustment because either condition may indicate a problem in that station's reference series we created. [1]

3. Results

The effect of these adjustments on individual stations were often significant, even to the point of changing the sign of the trend at that station. A plot of the trends in the maximum, minimum and DTR for annual temperature averaged over the Northern Hemisphere is shown in Fig. 1. This plot indicates that, when averaged over the entire hemisphere, our adjustments had only a marginal effect on the trends. In this case, the adjustments resulted in a slight increase in the slope for the maximum temperature (approximately +0.2°C/100 years), but had virtually no effect on the slopes for the minimum and DTR. This provides some verification of the robustness of previous results for large regions (hemispheric to global scale) obtained using data that were not tested for homogeneity.

However, when the results of analyses for different regions are examined it is clear that our homogeneity testing and adjustments can make a considerable impact. Figs. 2 and 3 show plots of the annual maximum, minimum, temperatures and range for two regions in China: the north/northwest region and the southeast region. In these two regions, the homogeneity testing and adjustments produce large changes in the slopes for linear trends in maximum and minimum temperature in both regions. However, in both regions there is not much difference in the slopes of the diurnal temperature range between the raw and adjusted data. This last point is somewhat surprising because minor changes in maximum and minimum temperature trends could significantly impact trends in the DTR. And indeed, in some other regions the sign of the linear trend in DTR changes after adjustments to the maximum and minimum temperatures.

[1] The dT/dt correlation coefficient is calculated using the year to year change in temperature time series derived from the candidate and from the reference time series. In this instance, the subsection refers to the section of the time series surrounding the discontinuity beginning at the previous discontinuity and ending with the next. We use the dT/dt correlation because it minimizes the effect of a discontinuity on the correlation coefficient.

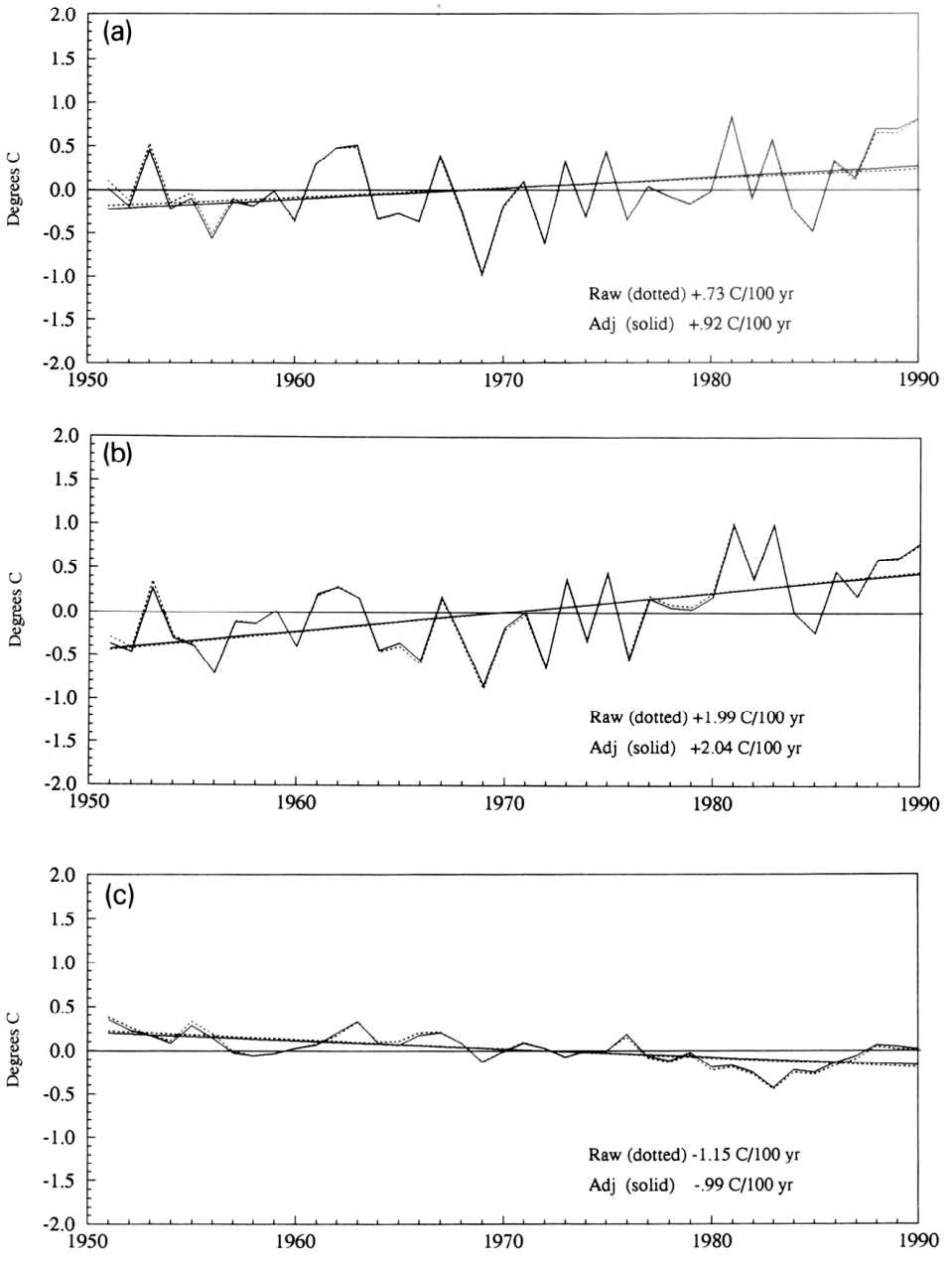

Fig. 1. Annual maximum (top) and minimum temperature (middle) and DTR (bottom) averaged over all available countries for the Northern Hemisphere.

Another interesting point, which was mentioned briefly in Karl et al. (1993) is the difference between these two regions in the trends for the maximum temperature. The slope for the DTR is very similar for each region, they are both decreasing at approximately 2–

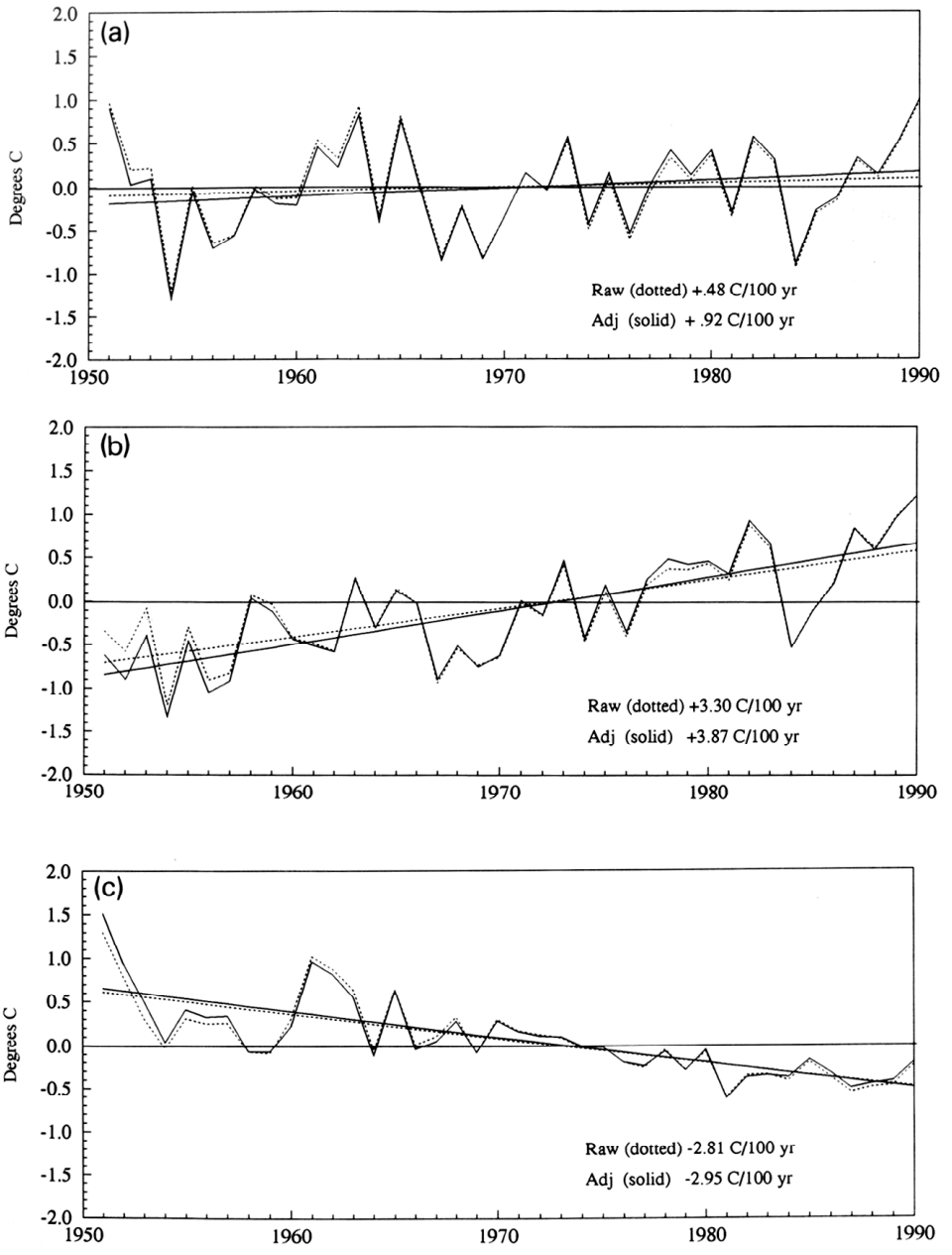

Fig. 2. Annual maximum (top) and minimum temperature (middle) and DTR (bottom) for Northwest China.

3°C/century. Yet, the DTR's are decreasing for different reasons. In the dry northwest China the maximum temperature is increasing, but the minimum is increasing at a faster rate. However, in the more moist southeast China the maximum temperature is decreasing

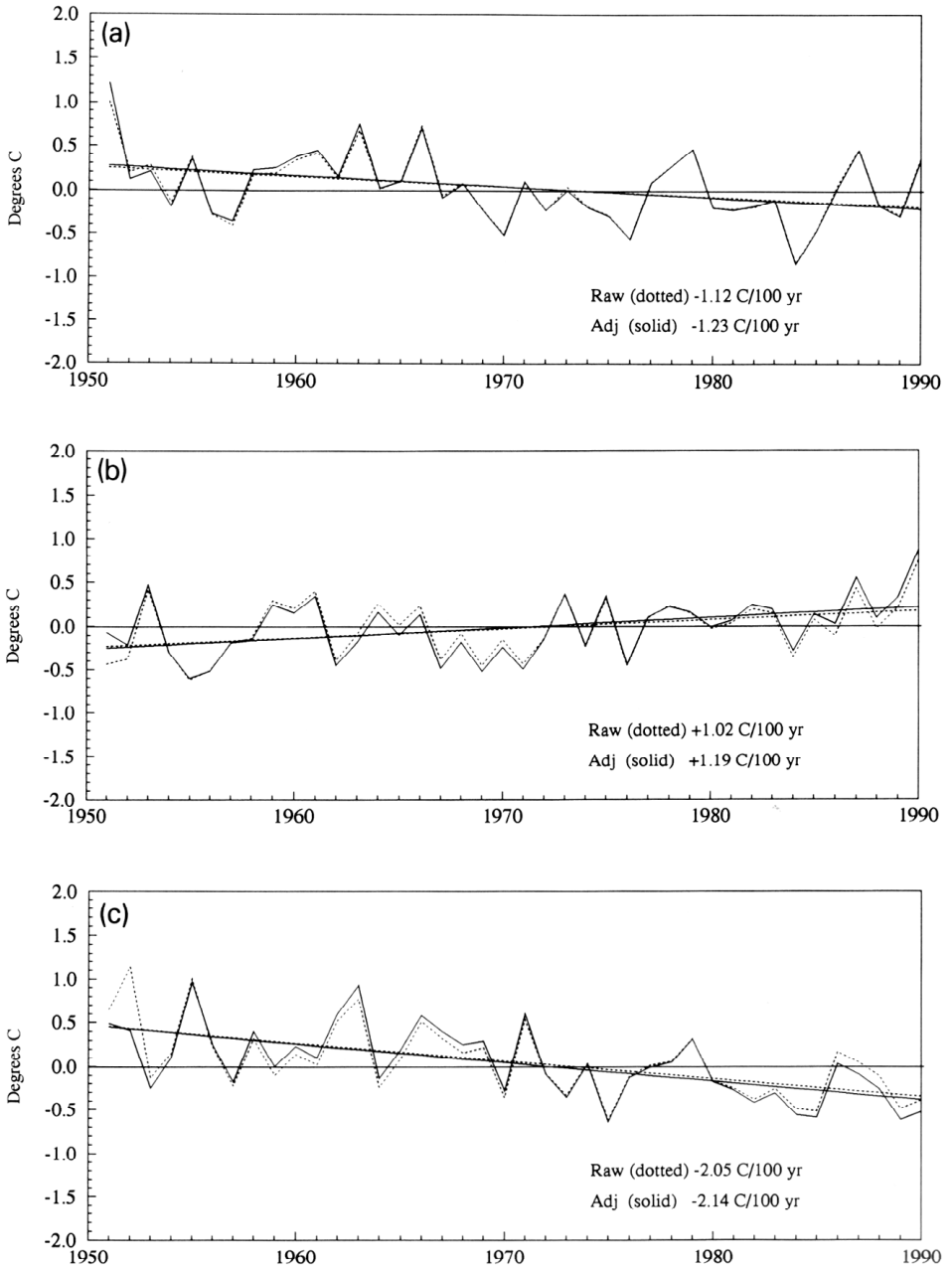

Fig. 3. Annual maximum (top) and minimum temperature (middle) and DTR (bottom) for Southeast China.

while the minimum temperature is increasing. We found similar differences between western Canada and eastern Canada and between western United States and eastern United States (see Table 1). Clearly these results indicate that either different physical mechanisms are at work or that effects from the same mechanism work differently in various regions.

Table 1
Trends in maximum and minimum temperature and diurnal temperature range (DTR) for both the original data and for data adjusted for artificial discontinuities for four regions in North America

	Max (orig/.adj.) °C/100 years	Min (orig./adj.) °C/100 years	DTR (orig./adj.) °C/100 years
Eastern Canada	−0.91/−0.87	−0.49/−2.13	−0.41/+1.27
Western Canada	+1.76/+2.55	+2.79/+2.20	−1.01/+0.38
Eastern USA	−0.34/−0.29	+0.46/+0.70	−0.78/−0.98
Western USA	+0.28/+0.48	+1.04/+1.25	−0.78/−0.76

4. Summary and conclusions

It has become increasingly apparent that the use of homogeneous climate data is critical in climate studies. A homogeneous data set can be achieved through careful station selection. However, given the wide array of factors that can cause discontinuities, it has been our experience that virtually every station we have examined contains some inhomogeneities. Therefore, we have chosen to systematically identify inhomogeneities and adjust the data to account for these discontinuities. The method we have used for homogeneity analysis of the data in this study is statistically based, objective, reproducible, and is designed to be applied to large climate data sets. Using this technique, we have evaluated and adjusted the majority of the maximum and minimum temperature data currently available in digital form for artificial discontinuities in station time series and reanalyzed the adjusted data.

The large-area (hemispheric to global) trends previously identified were essentially preserved in the adjusted data set, highlighting the robustness of earlier analyses using unadjusted though often carefully selected data. We therefore conclude that the trends in maximum and minimum temperature are not due to widespread systematic changes in instrumentation but rather climate change. However, for individual stations and climate regions within a country, adjustments for inhomogeneities can significantly alter the perceived trends in maximum and minimum temperature and trends in the DTR. Furthermore, regional differences in trends in the DTR may be the result of different physical mechanisms rather than the result of artificial discontinuities.

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